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Effects of Mechanical Scarification on Germination and Emergence of Switchgrass

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EFFECTS OF MECHANICAL SCARIFICATION ON GERMINATION AND EMERGENCE OF SWITCHGRASS

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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INTRODUCTION

Switchgrass, Panicum virgatum L., is a tall, perennial, warm-season, sod-forming species native to most of the United States east of the Rocky Mountains. It is an important species for livestock in the Great Plains, producing its greatest growth in the hot summer months when cool-season species are non-productive. As it is native to the Great Plains region, it exhibits ecotypic adaptability and forage production potential over a wide range of environmental and growing conditions. Because of its rhizomatous growth habit and fibrous root system, it is also useful for soil conservation purposes.

One of the problems associated with establishing native grasses in artificial seedings is related to dormancy mechanisms in their seeds. Native species are adapted to endure environmental changes in nature by having seeds that remain dormant until specific conditions are met. As a result, artificially planting certain native species often results in poor stand establishment. Seeds that germinate and emerge shortly after planting have the benefit of better temperature and moisture conditions needed for seedling growth.

Switchgrass, although easier to establish than certain other native species, often exhibits delayed and sporadic germination and emergence.

The main objective of this study was to evaluate mechanical scarification (cylinder scarification) for reducing seed dormancy, and for increasing rate of germination and seedling emergence of switchgrass. Promotion of rapid and uniform germination with a dormancy breaking procedure that was simple and feasible for large lots of seed was a final goal. Age of seed, storage

conditions, genetic background, and germination temperature were other factors evaluated for their influences on germination and emergence.

LITERATURE REVIEW

Permanent pasture, soil erosion control, reclamation of disturbed sites, and wildlife cover are important aspects of land management in the Great Plains. The establishment of grasses on barren rangeland and abandoned cultivated fields can help satisfy these needs. Paucity of well adapted introduced or cultivated warm season species makes it desirable to use native species which have become adapted to specific sets of environmental conditions and factors as a result of natural selection over time (Newell 1968). It is important to note that field evaluations of native grass seed moved too far north or south from their point of origin have demonstrated that ecotypic strains are adapted to limited geographic regions (Harlan 1962, Keim and Newell 1962).

Warm-season perennial grasses are an important part of the total native species resource (Warnes et al. 1971) and provide forage in the hot summer months when cool-season species are nonproductive. The lack of available forage in midsummer is an important limitation to the size of grazing herds (Griffin et al. 1980). In Pennsylvania, warm-season grasses produced 65 to 75% of their yield in midsummer. This is in contrast to cool-season species which made 60 to 66% of their production in May (Jung et al. 1978).

Switchgrass (Panicum virgatum L.) is one of the warm-season perennial species native to the Great Plains that offers great potential for use in pasture, hay, and range seedings (Eberhart and Newell 1959). As early as 1904, agrostologists noted the desirable characteristics of this species (Lyon and

Hitchcock 1904). It is one of the dominant species of the true or tall grass prairies and flood plains of the Great Plains (Weaver and Fitzpatrick 1932).

Switchgrass is distributed from Canada to Central America and from the Atlantic Coast to Nevada. It is usually found in large bunches and spreads by thick, scaly, creeping rhizomes. The inflorescence is a large open panicle (Hitchcock 1950). The functional, fertile floret consists of a hard, shiny lemma and palea tightly enclosing the caryopsis.

Switchgrass is adapted to a wide range in soil pH (4.9-7.6), precipitation (40-260 cm/yr), and average annual temperature (7-26°C) (Duke 1978). The successful occupation of a diversity of habitats over a great geographical range is reflected in the high degree of variability exhibited by this species (Porter 1966). Based on habitat and morphological characteristics, "upland" and "lowland" types have been described. Lowland types have been described as 0.6 to 3.0 m tall, robust, coarse, thick-culmed, with large wide panicles, longer leaves, and shorter rhizomes than upland types, and are found primarily on fine textured soils. Upland types have been described as 0.9 to 1.5 m tall, semidecumbent, fine-stemmed, early-maturing, and found on loamy or sandy soils (Church 1940, Cornelius and Johnston 1941, Eberhart and Newell 1959, Porter 1966).

Studies of chromosome numbers and plant variation on 59 isolates from Wisconsin to Arizona showed a polyploid series of 18 to 108 somatic chromosomes with no geographical segregation or morphological distinction on the basis of chromosome number (Nielsen 1944).

Agronomic characteristics

Several studies have shown the merit of utilizing switchgrass in pasture grazing programs.

In grazing trials in Missouri, Rountree et al. (1974) reported the carrying capacity of switchgrass and Caucasian bluestem (Bothriochloa intermedia (R. Br.) A. Camus) to be two to three times higher than that of 'alta' fescue (Festuca arundinacea Schreb.) from mid-July through September. Although response of warm-season species to nitrogen fertilization can be great (Balasko et al. 1984), significant summer forage yields with little fertilizer input have been reported (Balasko et al. 1984, Beaty and Powell 1976, Griffin and Jung 1981, Krueger and Curtis 1979). Krueger and Curtis (1979) reported average daily gains of yearling steers of 0.93 and 0.76 kg for switchgrass and big bluestem (Andropogon gerardii Vitman), respectively, in South Dakota, while Rountree et al. (1974) reported 0.8 to 1.8 lbs/day gain for cattle in Pennsylvania on switchgrass-and bluestem pastures. Evaluation of switchgrass forage quality by Newell and Moline (1978) showed average crude protein and in vitro dry matter disappearance (IVDMD) in mid July of 8.4 and 51.0%, respectively. If properly managed, stand life of switchgrass pastures may exceed 20 years (Soil Conservation Service 1969). Its tolerance to atrazine aids in weed control for establishment (Martin et al. 1982), and allows its use in grass waterways where herbicide runoff is a problem (Smith 1972). Heavy vigorous root systems and underground stems make switchgrass a valuable cover for soil conservation (Eberhart and Newell 1959).

Establishment

Establishment of switchgrass is slow and inconsistent when compared with cool season forages (Panciera and Jung 1984). Native grasses, including the warm-season species, are particularly slow to germinate (Warnes et al. 1971, Robocker et al. 1953). A property of seeds and seedlings important to establishment of the crop is vigor. Vigor as defined by Te May Ching (1973) is: "the potential for rapid uniform germination and fast seedling growth under general field conditions." As defined by Copeland (1976), seedling vigor can be measured by: (1) speed of germination, (2) uniformity of germination and plant development under nonuniform conditions, (3) ability to emerge through crusted soil, (4) germination and seedling emergence from cold wet pathogen-infested soils, (5) normal seedling morphological development, (6) crop yield, and (7) storability of seed under optimum or adverse conditions.

The positive relationship between speed of germination and seedling vigor is well documented (Copeland 1976). The speed of germination in forage species has been expressed mathematically by Maguire (1962). Germination and seedling growth are affected by factors such as seed size, dormancy in seeds, and environmental conditions.

Seed size

The relationship between seed size and seedling vigor has been evaluated by numerous researchers. Laboratory germination studies by Green and Hanson (1969) showed significant effects of seed size on speed of germination in sideoats grama (Bouteloua curtipendula (Michx.) Torr.), blue grama (Bouteloua gracilis (Willd, ex. H.B.K.) Lag. ex Steud.), Grenville switchgrass, switchgrass

A6606, and yellow Indiangrass (Sorghastrum avenaceum (Michx.) Nash. The heavier seeds of all five cultures germinated faster and produced larger seedlings than lighter seeds. Effect of seed weight varied greatly between species and between varieties within species. Emergence studies by Kneebone and Cremer (1955) showed seedlings from large seeds of buffalograss (Buchloe dactyloides (Nutt.) Engelm.), yellow Indiangrass, sand bluestem (Andropogon hallii Hack.), sideoats grama, and switchgrass emerged earlier and grew at a faster rate than seedlings from small seeds. Faster emergence of seedlings from larger seeds of various other grasses has also been reported (Rogler 1954, Vogel 1963, Whalley et al. 1966). Seed size has also been shown to affect mature plant traits (Kneebone 1972).

Dormancy

Of the several peculiarities of native grass seeds, the character of dormancy is primary in influencing stand establishment (Coukos 1944). Seed dormancy, as defined by Villiers (1972), is the state of arrested development whereby the organism, by virtue of its structure or chemical composition, may possess one or more mechanisms preventing its own germination. Nikolaeva (1969) listed four causes of seed dormancy when adequate moisture and temperature are provided: (1) properties of the outer covering of the embryo, (2) underdevelopment of the embryo, (3) physiological conditions, (4) combination of above factors.

In many species of plants, the seeds, when shed from the plant, will not germinate. These seeds will germinate under natural conditions if kept for a certain period of time. This period is known as afterripening. Afterripening

can be defined as any changes that occur in seeds during storage as a result of which germination is improved (Mayer and Poljakoff 1963). Changes that may take place include: differentiation at anatomical and morphological levels, or chemical or physical changes in the seed or its coat and breakdown of storage material (Mayer and Poljakoff 1963).

Delayed germination has been found in freshly harvested seed of cultivated crops such as winter wheat, oats, spring wheat, and rye, but the afterripening period does not persist long enough to interfere with stand establishment the first planting period following harvest (Coffman and Stanton 1938, Harrington 1923, Stone 1919). In many other grass species, freshly harvested seeds are dormant long enough to interfere with successful stand establishment. Coukos (1944) showed that seeds of big bluestem, little bluestem (Andropogon scoparius Michx.) and Indiangrass possessed prolonged dormancy. These seeds, stored at room temperature, did not begin normal germination until 14 to 18 months after harvest. Laude (1956) reported dormancy in freshly harvested seed of smilo grass (Oryzopsis miliacea (L.) Benth. and Hook.) and 12 annual grasses. The duration of delayed germination varied by species. For a given species, germination rate varied from year to year and among seed production locations. Thornton and Thornton (1962) concluded that freshly harvested seed of blue grama had a short duration of dormancy. Reports by Shaidaee et al. (1969) showed that one-year-old seed of sand bluestem, blue grama, and A6606 switchgrass, two-year-old seed of sideoats grama and yellow Indiangrass, and seven-year-old seed of Grenville switchgrass emerged best in field tests. Differences in success of emergence among and within species were noted. McAlister (1943) found that germination increased from 28% at four months after harvest to 98% after 58 months for green

needlegrass (Stipa viridula Trin.). Rogler (1960) found an average afterripening of seven years for green needlegrass with wide variation between strains and between year of harvest for new seed dormancy. Boe and Wynia (1982) reported age of seed as being a factor controlling rapid germination and vigor of switchgrass. Percent emergence in the greenhouse of three-, two-, and one-year-old seed was 86.0, 65.0, and 51.0, respectively. Wenger (1941) found buffalograss germination to increase with age for up to three years. Wright (1973) reported complete dormancy after harvest of Lehmann lovegrass (Eragrostis lehmanniana Nees). Dormancy was found to decrease in a linear pattern for 100 weeks after harvest.

Many times seed is needed promptly after harvest, or before the optimum afterripening period has passed. Temperature requirements and moisture conditions necessary for germination and seedling growth may be met for only a brief time in the field. Counts of live germinated seeds must be measured in the laboratory to insure suitability of seed for stand establishment. Because dormancy is detrimental to stand establishment, seed treatments to hasten germination have been sought.

Indian ricegrass (Oryzopsis hymenoides (Roem. & Schult.) Ricker)) is a native species with a high degree of dormancy. Toole (1940) found that prechilling increased germination, but dormancy was not totally removed by this method. Clark and Bass (1970) found that alternating temperatures promoted laboratory germination. McDonald and Khan (1977) stimulated germination of Indian ricegrass with gibberellic acid and kinetin. They found that abscissic acid inhibited germination. Studies by Zemetra et al. (1983) on various-aged seed, using various seed treatments, showed that concentrated sulfuric acid and a modified

commercial scarifier most effectively increased germination in the greenhouse. A rubbing machine was found to increase emergence in the field more than any other treatment. Concentrated sulfuric acid decreased field emergence of three age classes of seed in their study. In the many studies to improve Indian ricegrass germination in the laboratory, sulfuric acid has been most effective (McDonald and Khan 1977, Plummer and Frischknecht 1952, Stoddart and Wilkinson 1938, Zemetra et al. 1983). Removal of the lemma and palea with a knife (Stoddart and Wilkinson 1938) and rubbing seeds with emery cloth (Plummer and Frischknecht 1952) increased germination in some cases but caused increased embryo damage.

Kinch (1966) described a method to improve germination of western wheatgrass. He found that by clipping a small portion of the distal end of the caryopsis, germination was increased in laboratory studies. More fungual growth was noted in many trays. Considerable variability from sample to sample and year to year was found.

Fendall and Carter (1965) showed that germination of caryopses of green needlegrass with the lemma and palea removed began earlier and was much higher than for intact caryopses. This removal gave 50 to 100% germination of dormant and nondormant seed lots, respectively. Nielson and Rogler (1952) demonstrated improvement in the germination of new seeds by moist chilling for 10 to 50 days. Stratifying seed in moist sand for 60 days at 2 to 4°C resulted in higher germination of new seed (Rogler 1960). Fulbright and others (1983) found the greatest germination of the most dormant seed occurred when seeds were either prechilled or treated with a gibberellic acid and the lemma and palea were clipped with a razor blade. Wenger (1941) found that soaking buffalograss seed in tap water for two to four days and then drying prior to planting largely

overcame dormancy. Moist prechilling gave better germination for untreated seed than dry prechilling. He found older seeds needed shorter soaking time.

Laude (1951) investigated methods to improve stand establishment of smilo grass. In field trials, four weeks after planting, 3.8% of the untreated seeds emerged while 40.8 and 31.8% emerged for seeds soaked in 71% sulfuric acid and chlorox, respectively. Laude (1951) pointed out the ease of handling chlorox over sulfuric acid, thus making its use more advantageous.

Wright (1973) studied various pregermination treatments on Lehmann lovegrass. A moist prechill was effective in overcoming dormancy within 25 weeks after harvest. Needle scarification by hand with aid of a dissecting scope increased germination by 40%. (Cylinder scarification for seven- to twelve-seconds was the most effective and simplest of all treatments.)

Hauser (1981) concluded that germinated seeds of kleingrass (Panicum coloratum L.) and wintergreen hardinggrass (Phalaris aquatica L.) planted when the radicle began to emerge, established more seedlings than ungerminated seeds planted under wet and dry conditions. Machines for planting pregerminated seeds now exist.

Removal of the lemma and palea by rubbing between sandpaper and acid scarification for five minutes both hastened germination of dallis grass (Paspalum dilatatum Poir.) (Burton 1939).

Geng and Barnett (1969) noted that prechilling increased establishment of one cultivar of Indiangrass but another was unaffected. Studies by Byers (1973) found that Indiangrass seed soaked in 0.5% potassium nitrate solution for 24 hours followed by two week prechill increased germination by 25%. Five days in a high temperature (40°C) and humidity chamber (95% RH) increased germination by

28%. He also found hull removal increased germination 19% and clipping the caryopsis tip increased it by 6%.

Chemical scarification with sulfuric acid induced germination of dormant seed but was detrimental to nondormant seed of big bluestem, little bluestem, Indiangrass, and sideoats grama (Coukos 1944).

Mechanical scarification (scratching of the seedcoat) has been employed for many years to reduce the amount of hard seed in alfalfa (Medicago sativa L.). Because alfalfa seed quality deteriorates rapidly in storage following mechanical scarification, new ways to breed hard-seededness have been employed. Infrared, radiofrequency, and gas plasma treatments were effective in increasing germination in alfalfa (Nelson et. al. 1964).

Byers (1973) work with treatments to increase germination of switchgrass showed various potential methods. Fresh seeds of switchgrass soaked in 0.2% potassium nitrate solution for 24 hours followed by a six-week prechill increased germination by 40% and four days in high temperature (40°C) and humidity (95% RH) increased germination by 30%. Hull removal increased germination by 17% and clipping the caryopsis tip decreased germination by 5%. Thirteen month storage at 25°C increased germination by 77% while 13 month storage at -23°C increased germination 13%. Sautter (1962) experimented with effects of temperature, darkness, and scarification on germination of switchgrass. In one experiment the clasping lemma and palea were removed by rubbing the seeds between two sheets of emery cloth. Eighty-four percent emergence was obtained with this method. Three days after the experiment was started, 74% of the seeds had emerged. Chilling seed for 49 days before planting gave 76% germination and 50% germination was obtained with cold, dark period treatment. Darkness, constant temperature (27 to

29° C), constant freezing and thawing, and freezing night temperatures gave no improvement over the check.

Nakamura (1962) compiled a list of important forage grasses, their optimum germination temperatures, light requirements, and laboratory methods to break dormancy.

Environment plays a vital role in field establishment of a crop. The ability to break dormancy of seeds at a given time allows germination to be induced when environmental conditions are near optimum. Plummer (1943) has suggested that ideal planting dates for range grasses relates to temperature requirements for germination and seedling growth. Thus, laboratory studies can aid in determining optimum temperatures for planting. Various other factors, including variety, location of seed production, weed cover, soil type, and moisture affect germination and seedling growth.

MATERIALS AND METHODS

Set I

Set I was comprised of: (1) laboratory germination tests conducted each month from January through July, 1983, with the exception of March, (2) greenhouse emergence studies conducted concurrently with laboratory germination tests in January, February, and April, 1983, and (3) field emergence studies conducted concurrently with laboratory germination tests in June and July, 1983.

Seed lots used were: (1) Lot 1: 1981 Breeder's Seed of Sunburst (a large seeded, medium tall, medium maturity, upland type selected at the South Dakota Agricultural Experiment Station from a native southeastern South Dakota collection) kept in cold storage at 7°C and 43% RH since harvest in September 1981, (2) Lot 2: 1982 Breeder's Seed of Sunburst kept at room temperature since harvest in September 1982, (3) Lot 3: 1982 Breeder's Seed of Sunburst kept in cold storage at 7°C and 43% RH since harvest in September 1982, (4) Lot 4: 1981 Syn-1 Seed of SD 33 (an early-maturing, fine stemmed ecotype from southeastern North Dakota) kept at 7°C and 43% RH since harvest in August 1981, and (5) Lot 5: 1982 Syn-1 Seed of SD 33 kept at room temperature since harvest in August 1982. Seed weight for Sunburst lots was approximately 200 mg/100 seeds. SD33 lots weighed approximately 120 mg/100 seeds.

At each planting date, three random 5 g samples were obtained from each of the five seed lots, and subjected to one of the following: (1) no scarification (non), (2) 15 seconds of scarification in a Forsberg laboratory scarifier equipped with "Crystal Bay" 2/0 carborundum, and (3) 30 seconds of scarification (procedure same as 2).

For laboratory germination studies, six 100-seed (fertile floret) replicates of each seed lot X scarification treatment combination were planted on two blotters soaked in 0.2% KNO_3 solution in covered plastic germination boxes. Three replicates (boxes) of each seed lot X scarification treatment were placed in a completely randomized design on a shelf in an alternating temperature (15°C/16hr; 30°C/8hr) germinator. The remaining three replicates were placed in a completely randomized design on a shelf in a constant 20°C germinator. The alternating temperature germinator was equipped with fluorescent lighting which was on during the warm period. The constant temperature germinator was not illuminated. Germination was noted at 7, 10, and 14 days. Seeds were considered germinated when both radicle and coleoptile were visible.

For the greenhouse emergence studies (January, February, and April), three 25-seed replicates from the same 5 g seed lot X scarification samples used for the laboratory germination studies were planted in a completely randomized design in a 3 soil : 1 sand mixture in clay pots at a depth of 1.3 cm. Emergence was noted at 7, 10, and 14 days. Plants were considered emerged when the tip of the coleoptile became visible.

For the field emergence studies (June and July) ten 50-seed replicates from the same 5 g samples used for laboratory studies were planted in 0.6 m rows in a randomized complete block design with 0.3 m interrow and 1.0 m interblock spacings. The June planting was on a Lamour silty clay loam, nearly level (fine-silty, mixed (calcareous), frigid Cumolic Haplaquolls) soil approximately 2.0 km north of Brookings, SD. The July planting was on a Vienna loam, nearly level (fine - loamy, mixed udic Haploborolls) on the Agronomy Farm near the SDSU campus. Total numbers of seedlings/row were determined 30 days after planting.

Set II

Set II was comprised of: (1) laboratory germination tests conducted each month from October, 1983, through January, 1984, with the exception of December, and (2) a greenhouse emergence study conducted concurrently with the laboratory germination test in October 1983.

Seed lots used for this set were 1983 seed, harvested in September from a replicated variety yield trial at Brookings, of the following switchgrass varieties: (1) Variety 1: Sunburst (see Set I for variety description) (2) Variety 2: Pathfinder, a winter-hardy, leafy, late maturing, rust resistant type selected at Nebraska Agricultural Experiment Station from a domestic collection from Nebraska and Kansas, (3) Variety 3: Summer, a small-seeded, tall, leafy, late maturing type selected at the South Dakota Experiment Station from a native collection from Nebraska, (4) Variety 4: NDG-96598, early-maturing fine-stemmed type from North Dakota developed at the Plant Materials Center, SCS, at Bismark, ND. and (5) Variety 5: SD 149, a leafy upland type of medium height, selected at Plant Materials Center, SCS, Bismark, ND, from a native collection near Forestburg, SD.

Seedlot sampling, scarification procedures, laboratory germination, and greenhouse emergence studies were conducted as described for Set I.

Statistical Analyses

Germination at 14 days, greenhouse emergence, and field emergence data were subjected to analyses of variance. Treatment effects were compared using orthogonal contrasts. All variables were considered fixed in the analyses except for replications in the field which were considered random.

RESULTS

Set I

Laboratory Study

Mean germination percentages (Table 1) ranged from 0.7% (January, Lot 5, 20°C germinator) to 85.7% (February, Lot 1, 15/30°C germinator).

Orthogonal comparisons of scarification treatments (Table 2) showed that 15- and 30-second scarification treatments produced significantly ($p < 0.01$) higher germination percentage than nonscarified seed for all dates. Highly significant ($p < 0.01$) differences between 15- and 30-second scarification treatments were found for June and July plantings, and a significant ($p < 0.05$) difference was found between 15- and 30-second scarification treatments for the February planting. For all significant comparisons, the 30-second scarification treatment had the highest mean germination percentages. Mean percent germination exceeded 25% for 46.6, 86.2, and 100% of the non, 15-, and 30-second scarification experimental units, respectively. Overall mean germination percentages (averaged across seed lot, replication, date, and germinator temperature) for non, 15- and 30-second scarification treatments were 29.0, 49.5, and 53.2%, respectively.

Highly significant ($p < 0.01$) differences were found between germinator temperatures for all dates (Table 2), with seed incubated in the 15/30°C alternating chamber consistently exhibiting the highest mean germination percentages (Table 1). Mean percent germination exceeded 50% for 65.5 and 24.0% of seed incubated at 15/30 and 20°C, respectively. Overall mean germination percentages in the 15/30 and 20°C germinators were 54.6 and 32.3%, respectively.

Table 1. Laboratory mean percentage germination of nonscarified and scarified seed of five seed lots of switchgrass.

		Date of Test											
		January		February		April		May		June		July	
		Temperature C°											
Scarification	Lot	15/30	20	15/30	20	15/30	20	15/30	20	15/30	20	15/30	20
Seconds		%											
non	1	75.3	13.3	79.7	25.0	79.0	25.7	61.7	35.7	56.7	34.0	73.3	41.7
15	1	85.3	41.7	80.3	58.7	84.7	56.3	82.7	68.3	74.0	60.7	80.3	62.3
30	1	74.0	67.3	85.7	64.7	81.7	68.7	79.3	67.3	72.7	67.0	83.3	68.7
non	2	62.7	5.0	62.0	12.3	76.7	33.3	62.3	49.0	70.0	46.0	74.0	58.7
15	2	71.0	50.7	66.7	47.0	78.7	56.3	76.0	58.3	69.3	61.3	76.0	64.7
30	2	58.7	39.7	66.7	42.0	68.7	53.3	72.7	51.0	66.3	57.7	75.3	72.3
non	3	27.3	3.7	25.0	6.0	41.3	3.7	17.7	4.7	16.7	4.7	44.3	15.7
15	3	59.3	23.3	55.7	31.0	53.3	28.7	50.0	40.7	51.3	29.7	61.7	43.3
30	3	68.0	31.3	52.2	31.7	57.0	34.0	49.7	41.0	43.7	36.7	61.3	49.3
non	4			34.0	15.0	35.7	10.3	22.3	14.7	25.3	13.7	26.3	14.0
15	4			56.0	31.7	51.7	36.7	56.3	32.7	37.7	21.7	40.0	25.7
30	4			57.7	30.7	47.3	25.3	55.0	38.0	48.7	30.7	60.7	39.3
non	5	4.0	0.7	3.7	1.3	10.3	1.0	7.7	2.0	8.7	3.0	10.0	3.7
15	5	51.7	24.3	50.0	1.0	41.0	12.3	43.7	24.7	26.0	13.0	39.7	13.7
30	5	54.0	39.0	59.3	25.3	40.7	25.3	50.3	33.3	56.0	28.3	52.3	28.3

Table 2. Analyses of variance for laboratory germination of nonscarified and scarified seed of five seed lots of switchgrass incubated at two temperature regimes.

Source of Variation	df	Mean squares					
		January	February	April	May	June	July
Scarification	2	6536.1**	5537.2**	3379.9	6649.2**	4198.3**	4040.6**
non vs 15,30	1	12059.5**	10857.8**	6760.2**	13290.2**	7801.2**	7027.5**
15 vs 30	1	113.8	216.6*	0.8	2.9	595.3**	1050.8**
Lot	4†	3303.0**	4727.0**	6396.9**	5528.6**	6338.0**	7372.7**
1 vs 3	1	5184.0**	9250.6**	7933.5**	9135.5**	8306.5**	4491.7**
1,2,3 vs 4,5	1		7886.8**	15022.0**	10509.9**	13462.2**	22093.6**
4 vs 5	1		1786.7**	1458.5**	820.8**	457.5**	848.6**
1,3 vs 2	1		0.5	1198.8**	1628.7**	3114.4**	2049.9*
Temperature	1	15429.4**	16919.5**	14187.8**	5107.6**	4622.5**	6620.0**
Scarification x Lot	8†	291.9**	159.3**	133.7**	242.4**	341.0**	200.7**
Scarification x Temperature	2	480.1**	23.6	493.7**	25.4	6.1	29.1
Lot x Temperature	4†	422.4**	104.8*	144.9**	41.3	3.9	91.7*
Scarification x Lot x Temperature	8†	576.9**	452.1**	183.0**	66.9*	128.2**	116.8**

*,** Significant at the 0.05 and 0.01 levels, respectively.

† df were 3,6,3,6 for lot, scarification x lot, lot x temperature, and scarification x lot x tempertaure, respectively for January.

Seed lot effects on germination were highly significant ($p < 0.01$) for all dates (Table 2). Overall mean germination percentages were 24.7, 34.5, 36.0, 58.7, and 64.3% for Lots 5, 4, 3, 2, and 1, respectively. Comparison of seed lot mean germination percentages using orthogonal contrasts (Table 2) revealed highly significant ($p < 0.01$) differences between Lots 1 and 3 at all dates and 1, 2, and 3 and 4 and 5 at all dates.

Seed lot X scarification and scarification X seed lot X temperature interaction effects were significant for all dates. Scarification X temperature effects were significant for the January and April plantings and seed lot X temperature effects were nonsignificant for only May and June plantings.

Greenhouse Study

Mean percent emergence in the greenhouse ranged from 0.0% (January and February, Lot 5, nonscarified) to 86.7% (April, Lot 2, nonscarified) (Table 3).

Analyses of variance indicated highly significant ($p < 0.01$) differences among scarification treatments for January and February plantings (Table 4). Orthogonal contrasts (Table 4) revealed a highly significantly ($p < 0.01$) lower emergence percentage for non compared to 15- and 30-second treatments for these dates. The orthogonal comparison of 15- and 30-second treatments was significant ($p < 0.05$) for the January planting with the 30-second treatments yielding the highest overall emergence percentages. Mean percent emergence exceeded 25% for 35.7, 78.6, and 85.7% of the non, 15- and 30-second scarification treatments, respectively. Overall mean emergence percentages were 25.3, 41.5, and 42.0% for non, 15- and 30-second scarification, respectively.

Analyses of variance revealed highly significant ($p < 0.01$) differences among seed lots for all dates (Table 4). Orthogonal contrasts showed highly

Table 3. Greenhouse mean percentage emergence of nonscarified and scarified seed of five seed lots of switchgrass.

Scarification	Lot	Date of Test		
		January	February	April
Seconds			%	
non	1	24.0	18.7	73.3
15	1	36.0	54.7	84.0
30	1	34.7	49.3	72.0
non	2	10.7	9.3	86.7
15	2	12.0	33.3	73.3
30	2	26.7	13.3	60.0
non	3	4.0	2.7	54.7
15	3	17.3	18.7	68.0
30	3	29.3	17.3	49.3
non	4		10.7	42.7
15	4		30.7	60.0
30	4		41.3	66.7
non	5	0.0	0.0	32.0
15	5	32.0	28.0	50.7
30	5	37.3	36.0	64.0

Table 4. Analysis of variance for greenhouse emergence of nonscarified and scarified seed of five seed lots of switchgrass.

Source of Variation	df	Mean Squares		
		January	February	April
Scarification	2	1545.3**	2889.6**	326.8
non vs 15,30	1	2736.5**	5760.0**	480.2
15 vs 30	1	353.0**	19.2	172.8
Lot	4†	448.6**	1027.2**	1261.0**
lot 1 vs 3	1	972.4**	3528.0**	1641.6**
lots 1,2,3 vs 4,5	1		1.0	2885.3**
lots 4 vs 5	1		175.2	257.9
lots 1,3 vs 2	1		410.4	249.9
Scarification x Lot	8†	175.3*	193.6*	462.3**

*,** Significant at 0.05 and 0.01 levels, respectively.

† Df were 3 and 6 for Lot and Scarification x Lot, respectively for January.

significant differences between Lots 1 and 3 at all dates and 1, 2, and 3 and 4, and 5 at the April planting. Overall mean emergence percentages were 29.0, 31.1, 36.1, 42.0, and 49.6% for seed lots 3, 5, 2, 4, and 1, respectively. Seed lot X scarification interaction effects were significant ($p < 0.05$) at the January and February planting and highly significant ($p < 0.01$) for the April planting.

Field Study

Mean percent emergence ranged from 7.1% (Site 1, Lot 5, nonscarified) to 67.1% (Site 1, Lot 1, 15-second scarification) (Table 5).

Scarification significantly ($p < 0.01$) increased emergence at Site 1 but not at Site 2 (Table 6). Orthogonal comparisons for Site 1 (Table 6) were highly significant ($p < 0.01$) for non versus 15- and 30-, and 15- versus 30-second scarification. Fifteen-second scarification gave higher mean percent germination for all seed lots except for Lot 5 at Sites 1 and 2 (Table 5). Overall mean percent emergence for non, 15-, and 30-second scarification was 34.8, 41.6, and 36.6%, respectively.

Seed lot effects were highly significant ($p < 0.01$) at Sites 1 and 2 (Table 6). Comparison of mean emergence percentages (Table 6), using orthogonal comparisons showed Lots 1 and 3, and 1, 2, and 3 versus 4 and 5 were significantly ($p < 0.01$) different at both sites. Overall mean percent emergences considering both sites were 22.3, 29.6, 35.9, 45.8 and 54.7% for seed lots 5, 4, 3, 2, and 1, respectively.

Seed lot X scarification effects were highly significant ($p < 0.01$) at Site 1 but not at Site 2 (Table 6).

Table 5. Field mean percentage emergence of nonscarified and scarified seed of five seed lots of switchgrass.

Scarification	Lot	Location of Test	
		Site 1	Site 2
Seconds		%	
non	1	57.7	47.0
15	1	67.1	58.2
30	1	50.0	48.2
non	2	54.6	43.4
15	2	52.8	39.0
30	2	45.7	39.0
non	3	32.0	42.0
15	3	40.6	41.6
30	3	27.4	32.0
non	4	22.8	24.2
15	4	38.6	29.0
30	4	34.8	28.4
non	5	7.1	17.8
15	5	25.1	23.6
30	5	35.1	25.2

Table 6. Analyses of variance for field emergence of nonscarified and scarified seed of five seed lots of switchgrass.

Source of Variation	df	Mean Squares Site 1	Site 2
Scarification	2	892.6**	212.5
non vs 15,30	1	1105.9**	79.0
15 vs 30	1	679.4**	346.0
Lot	4	4561.8**	3924.2**
lot 1 vs 3	1	9330.0**	1667.0**
lots 1,2,3 vs 4,5	1	14825.5**	8790.2**
lot 4 vs 5	1	975.8**	375.0
lots 1,3 vs 2	1	382.9	380.2
Replication	9†	2828.2	337.1
Scarification x Lot	8	492.8**	192.7
Scarification x Replication	18†	55.6	137.2
Lot x Replication	36†	98.9	184.5
Scarification x Lot x Replication	72†	122.1	126.2

*,** Significant at 0.05 and 0.01 levels, respectively.

† Df were 6, 12, 24, 48 for Replication, Scarification x Replication, Lot x Replication, and Scarification x Lot x Replication, respectively for Site 1.

Set II

Laboratory Study

Mean percent germination ranged from 0.0 (January, Variety 1, nonscarified, 20°C germinator) to 87% (January, Variety 3, 15-second scarification, 15-30°C germinator) (Table 7).

Analyses of variance revealed scarification treatments to be highly significantly ($p < 0.01$) different for all dates (Table 8). Orthogonal comparisons (Table 8) of non versus 15- and 30- and 15- versus 30-second scarification were highly significantly ($p < 0.01$) different at all dates. (Replication X germinator temperature X variety combination) means showed 30-second scarification to yield higher percent germination for the October and November planting, and 15-second scarification yielded higher mean percent germination for the January planting. Overall mean percent germination for nonscarified seed was 8.7%, while 15- and 30-second scarification yielded 39.5 and 39.0%, respectively.

Germinator temperature effects were highly significantly different ($p < 0.01$) for all dates (Table 8). Mean percent germination was highest for all non and scarified seeds in the 15/30°C germinator. Overall mean germination percentages were 37.8 and 20.4% for 15/30 and 20°C, respectively.

Variety effects were highly significant ($p < 0.01$) for all dates (Table 8). Highest overall mean germination percentage for varieties was 36.1% (Pathfinder) and the lowest was 22.1% (SD 149).

Variety X scarification effects were highly significant ($p < 0.01$) for all dates. Variety X temperature effects were highly significant ($p < 0.01$) at the October and January planting, and temperature X scarification effects were highly significant ($p < 0.01$) for the October and November plantings (Table 8).

Table 7. Laboratory mean percentage germination of nonscarified and scarified seed of five varieties of 1983 freshly harvested seed of switchgrass incubated at two temperature regimes.

		Date of Test					
		October		November		January	
		Temperature C°					
Scarification	Variety	15/30	20	15/30	20	15/30	20
Seconds		%					
non	Sunburst	6.0	1.3	7.3	1.3	22.7	0.0
15	Sunburst	55.3	30.3	57.7	31.3	67.7	47.0
30	Sunburst	58.3	35.0	53.3	39.3	75.0	41.0
non	Pathfinder	10.0	3.3	10.7	2.0	36.3	3.7
15	Pathfinder	61.0	40.7	34.7	17.0	83.0	60.3
30	Pathfinder	62.7	48.3	32.3	24.7	73.3	46.0
non	Summer	2.7	0.7	24.0	0.0	42.0	2.0
15	Summer	8.3	3.7	28.0	11.7	87.0	53.7
30	Summer	7.3	1.7	32.7	20.3	65.0	19.7
non	NDG-96598	9.3	4.0	7.0	0.7	28.7	1.3
15	NDG-96598	18.3	8.0	59.7	36.7	76.3	58.0
30	NDG-96598	15.0	9.7	43.0	33.0	66.0	51.0
non	SD 149	5.7	1.7	10.7	4.0	9.0	1.7
15	SD 149	23.3	6.0	37.3	21.7	43.3	16.3
30	SD 149	37.7	17.3	61.0	33.0	43.3	25.0

Table 8. Analysis of variance for laboratory germination of nonscarified and scarified seed of 1983 freshly harvested seed of switchgrass incubated at two temperature regimes.

Source of Variation	df	Mean Squares		
		October	November	January
Scarification	2	5367.7**	8272.7**	16705.6**
non vs 15,30	1	10515.7**	16347.8**	32272.6**
15 vs 30	1	216.6**	205.3**	1145.8**
Variety	4	3584.9**	573.2**	2066.3**
Temperature	1	2876.4**	4928.4**	15366.4**
Scarification x Variety	8	836.3**	473.8**	412.0**
Scarification x Temperature	2	262.3**	173.7**	24.4
Variety x Temperature	4	139.0**	28.8	327.2**
Scarification x Variety x Temperature	8	32.6	90.7**	87.9**

*,** Significant at 0.05 and 0.01 levels, respectively.

Greenhouse Study

Mean emergence percentages ranged from 0.0 (nonscarified, NDG-96598) to 58.7% (15-second scarification, Pathfinder) (Table 9).

Scarification effects were found to be highly significantly different ($p < 0.01$) (Table 10). Orthogonal contrasts (Table 10) revealed that 15- and 30-second scarification treatments produced significantly higher germination percentages than nonscarification. Significant differences ($p < 0.05$) between 15- and 30-second scarification were found, with 15-second scarification producing the highest mean germination percentage. Overall percent mean emergence for non, 15-, and 30-second scarification were 7.2, 24.8, and 18.0%, respectively.

Variety effects were highly significantly ($p < 0.01$) different (Table 10). Overall mean percent emergence for varieties ranged from 5.3 (Variety 4) to 37.3% (Variety 2).

Variety X scarification effects were found highly significantly ($p < 0.01$) different (Table 10).

Table 9. Greenhouse mean percentage emergence of nonscarified and scarified seed of five varieties of 1983 freshly harvested seed of switchgrass.

Scarification	Variety	Date of Test October
Seconds		%
non	Sunburst	3.3
15	Sunburst	32.7
30	Sunburst	26.7
non	Pathfinder	20.0
15	Pathfinder	58.7
30	Pathfinder	33.3
non	Summer	7.3
15	Summer	8.7
30	Summer	5.3
non	NDG-96598	0.0
15	NDG-96598	6.0
30	NDG-96598	10.0
non	SD 149	4.0
15	SD 149	20.0
30	SD 149	18.8

Table 10. Analysis of variance for greenhouse emergence of nonscarified and scarified seed of five varieties of 1983 freshly harvested seed of switchgrass.

Source of Variation	df	Mean square October
Scarification	2	1212.8**
non vs 15,30	1	2016.4**
15 vs 30	1	346.8*
Variety	4	1370.1**
Scarification x Variety	8	264.3**

*, ** Significant at 0.05 and 0.01 levels, respectively.

DISCUSSION

The ability of certain plants to delay seed germination until a specific combination of environmental and physiological conditions is met is an important survival mechanism. Dormancy is a method by which plants endure periodic and nonperiodic changes in their environment (Koller 1972, Villiers 1975, Copeland 1976). While dormancy prevents preharvest sprouting in cereals and allows seeds to remain viable for extended periods of time in soil, extended dormancy is undesirable when a species is artificially seeded. Seedling vigor is an important criterion for successful establishment of grasses in harsh environments of the Northern Great Plains. Speed of germination is an important aspect of seedling vigor (Copeland 1976). When speed of germination is delayed by dormancy, stand establishment is often poor. Dormancy is generally characteristic of native grasses and is a primary factor affecting establishment (Coukos 1944).

The outer coverings of the embryo are partially responsible for dormancy in various grasses (Zemetra et al. 1983, Kinch 1966, Fendall and Carter 1965, Wright 1973, Burton 1939, Byers 1973, Sautter 1962, Laude 1951). According to Bewley and Black (1982), coverings of the embryo may inhibit germination by interfering with water uptake or gas exchange, by containing chemical inhibitors, by acting as a barrier against escape of inhibitors from the embryo, by modifying light reaching the embryo, or by exerting mechanical restraint

Switchgrass can be slow to germinate and emerge. The seed unit is a floret with a shiny, glabrous, firm lemma clasping the palea with thick inrolled margins. The lemma and palea tightly enclose the caryopsis. In this study, structure of the seed unit was hypothesized to be a factor contributing to

reduction of germination and emergence. The tight adherence nature and firmness of the lemma and palea were assumed to inhibit germination of the caryopsis.

Set I

Laboratory and Greenhouse Study

Scarified seed consistently germinated higher than nonscarified seed in the laboratory. Germination in the alternating temperature germinator (15°C/16 h; 30 C/8 h, a standard procedure for laboratory testing of switchgrass (AOSA 1981), increased from 41 to 61% germination as a result of scarification. Byers (1973) reported that under similar laboratory conditions hull removal increased germination of switchgrass from 27 to 44%.

Considering both temperature regimes, overall germination was increased from 29.0% for nonscarified seed to 49.5 and 53.2% for 15- and 30-second scarification, respectively in the laboratory. Scarification increased greenhouse emergence, except in April. Overall, emergence was 25.3, 41.5, and 42.0% for non, 15-, and 30-second scarification, respectively. Mean emergence in the greenhouse was increased by as much as 37.3% (Lot 5, January, 30-second scarification) while that in the laboratory was increased by as much as 55.6% (Lot 5, February, 30-second scarification, 15/30°C germinator. Sautter (1962), in an unreplicated greenhouse test, showed an 84% increase in emergence after rubbing switchgrass seeds between emery cloths to remove the lemma and palea. This substantial increase indicated a high degree of dormancy caused by the floret bracts of the particular lot of seed being tested.

Laboratory and greenhouse data from this study indicate that the lemma and palea are at least partially responsible for depressing germination and emergence

in switchgrass. However, neither complete removal of the lemma and palea (Sautter 1962) nor scarification appear to be able to remove all dormancy. Viability tests (tetrazolium tests for example) could aid in determining what portion of the live seeds remained ungerminated after hull removal or scarification. This would give an estimate of the amount of dormancy related to the lemma and palea.

Age of seed had a significant effect on germination and emergence in the laboratory and greenhouse for Sunburst. Freshly harvested seeds of many grasses require an afterripening period in which physiological and morphological changes take place before adequate germination or emergence occurs (Coukos 1944, Laude 1951, Shaidaee et. al. 1969, Zemetra et al. 1983, Wenger 1941, Rogler 1960, Harty and Butler 1975). In this study, comparison of 1981 (Lot 1) and 1982-harvested Sunburst (Lot 3), both stored at 7° C and 43% RH since harvest, indicated Lot 1 germinated and emerged significantly greater than more recently harvested seed (Lot 3). Overall mean germination for nonscarified seed of 1981-harvested Sunburst (Lot 1) was 50.1% while that of 1982-harvested seed (Lot 3) was 17.6%. In the greenhouse, overall emergence for nonscarified seed was 38.7 and 20.5% for Lot 2 and Lot 3, respectively. Germination and emergence of scarified seed were also consistently higher for the older lot. Highly significant ($p < 0.01$) orthogonal comparisons of Lot 1 and Lot 3 also indicated variability in germination between the two ages of seed in the laboratory and greenhouse.

In the laboratory, the overall increase in germination as a result of scarification was greater for 1982 (Lot 3) than for 1981-harvested Sunburst (Lot 1) for both 15- and 30-second scarification. In the greenhouse the opposite occurred, with Lot 1 showing the greatest response after scarification. In the

greenhouse, Lot 3 may have germinated in the soil but could not emerge. This does not appear to be the reason, however, as abnormal sprouts in the laboratory were not abundant for this seed lot. As seed was harvested from the same field for the consecutive years of harvest and conditions were not drastically different for the two years, difference in germination appears more related to aging than environmental factors. If germination tests of Lot 1 would have been conducted shortly after harvest, the influence of environmental conditions during seed production could have better been addressed. Boe and Wynia (1982) showed percent germination increased significantly with age of seed in comparing 3-, 2-, and 1-year old and freshly harvested seed of Sunburst. Percent emergence in the greenhouse also increased with age of seed. Three-, two- and one-year old seed lots exhibited 86.0, 65.0 and 51.0% emergence, respectively. Emergence of freshly harvested seed was 4.0%. McWilliams (1950) also reported an increase in germination with age of seed in switchgrass. In a ten year study, germination increased for up to ten years and was greatest at four to eight years.

Storage conditions also affected germination and emergence of nonscarified and scarified seed. In the laboratory, seed of 1982-harvested Sunburst (Lot 2) stored at room temperature, where temperature and humidity varied, germinated 51.0, 64.7, and 60.4% for non, 15-, and 30-second scarification, respectively. In the greenhouse these two lots were not found statistically different except in April. Numerically, emergence of nonscarified seed was always greatest for the 1982-harvested Sunburst kept at room temperature. Lot 2 stored at room temperature exhibited greenhouse emergence of 35.5, 39,5, and 33.3% for non, 15-, and 30-second scarification, respectively. The increase in germination and

emergence in the laboratory and greenhouse as a result of scarification was low for Lot 2 compared to Lot 3.

These findings are in agreement with others who found big bluestem, little bluestem (Coukos 1944), and sideoats grama (Sumner 1962) retained dormancy and viability longer if kept under low temperature and relative humidity. Relative humidity and temperature are the principal external factors that influence seed longevity (Copeland 1976, Harrington 1923a). Logically, conditions that slow down or speed up deterioration of seeds would do the same in the breakdown of dormancy.

Faster breakdown of inhibiting properties of the embryo coverings may have occurred at room storage as well as physiological changes affecting the embryo, making initial germination and emergence high, but response to scarification low (for Lot 2). Storage of seeds for longer periods of time at room temperature may show a decrease in viability and even less response to scarification. This was not tested in this study, however.

In both laboratory and greenhouse studies, overall germination and emergence of nonscarified seed of 1981-harvested Sunburst (Lot 1) were similar to that of 1982-harvested seed stored at room temperature (Lot 2). Scarified seed of the 1981 Sunburst (Lot 1) had a greater germination and emergence than scarified seed of the 1982-harvested lot stored at room temperature (Lot 2). In comparing the 1981-harvested SD33 syn-1 stored in the cold room (Lot 4) to 1982-harvested SD33 syn-1 stored at room temperature (Lot 5), the nonscarified seed produced dissimilar germination and emergence percentages of 21.1 and 4.7% for Lot 4 and Lot 5, respectively, in the laboratory and emergence percentages of 26.7 and 10.7% for Lot 4 and Lot 5 in the greenhouse, respectively. For the

scarified seed, the highest germination and emergence were for the 1981 SD33 syn-1. The increase in both laboratory germination and greenhouse emergence as a result of scarification was greatest for 1982-harvested SD33 syn-1 stored at room temperature (Lot 5). Storage at higher temperature and humidity did not affect the particular lot of SD33 syn-1 used, contrary to results obtained for Sunburst. The degree of dormancy for SD33 syn-1 (Lot 4 and Lot 5) appears to be greater than that of Sunburst as percentages of germination and emergence were lower. Dormancy related to the embryo and to restrictive coverings both appeared to be involved. Embryo dormancy in these lots of SD33 syn-1 (Lot 4 and Lot 5) may have been much deeper than in Sunburst and the breakdown of this dormancy much slower. Dormancy due to restrictive coverings (lemma and palea) was also much greater and breakdown was slower. As a result, storage at room temperature did not break down dormancy related to restrictive coverings as much or as fast, and response to scarification was thus greatest for the more freshly harvested seed of SD33 syn-1 stored at room temperature (Lot 5). Environment could have also been an important factor in differences between germination and emergence of the 1981- and 1982-harvested SD33 syn-1.

A laboratory accelerated aging technique of exposing seeds to 5 days of high temperature and humidity (40°C and 95% R.H.) prior to planting was effective in increasing germination of wheat (Delouche 1967) but decreased germination and number of total viable seed of 11 month old switchgrass (Byers 1973).

Germination capacity of seeds is strongly influenced by environmental factors such as temperature and water stress which may interact in their effects (McGinnies 1960, Tadmore et al. 1969). Optimum temperature for germination is not the same for all species or ecotypes within species. A change in temperature

is effective in promoting germination of some species. The need for alternating temperatures is not well understood. Copeland (1976) relates this need to embryo dormancy, while others associate the permeability of membranes surrounding the embryo (Bewley and Black 1982) with response to alternating temperatures. According to Morinaga (1926), in some seeds the need for alternating temperatures is entirely imposed by the seed coat and this need disappears if the coats are broken. Poorly ripened (Chippindale 1949) and slowly germinating seeds (Harrington 1923b) have been found more responsive to alternating temperatures than ripened or vigorous seed. Alternating temperatures are used for standard laboratory germination for testing many trees and grasses. Conditions of 15°C/16 h; 30°C/8 h are used in standard laboratory testing of switchgrass (AOSA 1981). In this study, germination in the alternating temperature germinator was consistently higher than the 20°C constant germinator for nonscarified and scarified seed. Overall mean germination in the alternating chamber was 41.2, 60.3, and 62.0% for non, 15-, and 30-second scarification, respectively while that in the 20°C constant temperature germinator was 17.4, 37.4, and 44.4%. Ahring and coworkers (1959) found constant temperature of 20°C resulted in less than 50% germination of six month-old switchgrass seed but alternating temperature of 20/35°C increased germination to 80%. Nakamura (1962) noted the effectiveness of alternating temperatures for germination of switchgrass, and Boe and Wynia (1982) found germination of switchgrass significantly higher under alternating temperatures compared to constant temperatures. Germination of several cool- and warm-season grasses was better at alternating temperature than constant temperature (McElgunn 1974, Harty and Butler 1975).

In this study, only seeds that appeared ripe were used, so response to alternating temperatures did not seem related to ripeness. More readily germinating seeds of 1981-harvested Sunburst (Lot 1), for example, responded no greater to alternating temperatures than the 1982-harvested seed (Lot 3) thus differing from findings of Harrington (1923b) on other species. The need for alternating temperature was not entirely imposed by the lemma and palea or seed covering, as germination of scarified seed in the alternating germinator was greater than for nonscarified seed, and germination of scarified seed in the 20°C germinator did not equal germination of nonscarified seed in the alternating germinator.

Temperature by itself also appears to be an important factor. According to Hsu and coworkers (1985), germination of Cave-in-rock and Blackwell switchgrass that had been chilled for 2 weeks at 4°C prior to germination tests, was not improved as a result of alternating temperature of 30/20°C compared to germination at constant temperature between 20 and 30°C. For unchilled seeds, constant temperatures producing the greatest germination were between 12 and 25°C. Varietal differences were found for response to temperatures.

The greatest germination percentage in this test was in the alternating temperature germinator. However, standard tests such as those used in this study may indicate germination ability but may not be adequate indicators of successful field emergence. As found by Mark and McKee (1968) standard tests usually do not evaluate seedling vigor and field emergence as accurately as other methods.

As was previously discussed, age of seed and storage conditions are important factors affecting degree of dormancy exhibited by a particular lot of seed. Dormancy is variable from year to year among and within varieties of a

species (Kinch 1966, Wright 1973, Richter and Switzer 1982). Although the specific conditions for induction of dormancy are not well understood, environmental conditions during seed development are known to be important factors (Villiers 1975, Copeland 1976).

Sunburst (Lots 1, 2, and 3) and SD33 syn-1 (Lots 4 and 5), varied in degree of dormancy. Genetic variation between them is an important contributing factor.

Kneebone and Cremer (1955) concluded that the larger seeds of a species produced more vigorous seedlings and gave better assurance of a stand than smaller seeds. Green and Hanson (1959) found heavy seeds of a variety germinated faster than light seeds, but the effect of seed weight varied greatly between varieties within a species. For example, Grenville switchgrass had a 3% difference in germination between light and heavy seeds while A-6606 switchgrass had a difference of 50%. The light seeds of Grenville switchgrass had a 9% greater germination than heavy seeds of A-6606 (Grenville had the heavier seed overall). Johnson and Boe (1982) found a highly repeatable seed size variation among and within three varieties of switchgrass.

As Sunburst seeds are larger than SD33 syn-1, seed size may be an important factor in the difference of germination and emergence of these two ecotypes.

The length of scarification treatment is critical and varies depending on degree of dormancy exhibited by the seed lot and on surface area of the seed. The type of dormancy is also important.

In this study, neither length (15- and 30-second) of scarification was consistently superior for increasing germination or emergence for all lots tested. For many of the testing dates, the results of 15- and 30-second scarifi-

cation were not significantly different from each other. However, in the laboratory, less than 6% of the scarified seed tested germinated at a rate lower than nonscarified seed. Greenhouse emergence for scarified seed was lower than for nonscarified seed only 14% of the time.

Seed of 1982-harvested SD33 syn-1 stored at room temperature (Lot 5) was the most dormant seed lot in this study. Increasing the length of scarification improved laboratory germination and greenhouse emergence for most trials. Response to scarification for this lot was always greater than for the other lots tested. As SD33 syn-1 seed was smaller than Sunburst, length of scarification could affect seeds differently. As response to increasing scarification time was greater for SD33 syn-1 (Lot 5), dormancy related to restrictive coverings appears to be greater. In studies using cylinder scarification for reducing dormancy of Lehmann lovegrass, specific ranges of scarification time and volumes were found important for optimum benefit (Wright 1973). Optimum scarification length for specific switchgrass varieties may be a priority in future research related to use of cylinder scarification for enhancing germination and emergence.

Emergence in the greenhouse was much lower than laboratory germination in the alternating temperature germinator except for the April planting. Emergence was much higher for the April planting compared to January and February (Table 3). Sunnier conditions in the greenhouse at this time of year probably warmed the soil much faster and to a greater degree causing more rapid and greater emergence.

Field Study

Field results were less consistent than those obtained in the laboratory and greenhouse. Environmental conditions at planting and during seedling emergence were important factors contributing to this inconsistency. At Site 1, seeds were planted during the late spring as recommended. However, weed competition was severe and rainfall slight following seeding. As found for many warm-season grass seedlings, competition from weeds can be severe (Warnes et al. 1971). Samson and Moser (1982) also found competition from sod detrimental to switchgrass seedlings. Use of atrazine, which has been found acceptable for use in switchgrass establishment (Martin et al. 1982) could have eliminated some of the weed competition.

At Site 2, seed was planted late in the season. Emergence at this Site was neither consistently higher nor lower than for the earlier planting at site 1. Panciera and Jung (1984), found seeding year yield for switchgrass declined as planting date advanced into the summer. They also found varietal differences in reaction to planting dates. Blackwell, for example, was easier to establish because of its adaptation to a wider range of planting dates than KY 1625.

Results of tests by Vassey and coworkers (1985) conducted to evaluate seeding dates and seeding rates on establishment of switchgrass, showed seeding during mid to late April or early May in Iowa was most successful as precipitation patterns were more favorable for germination and early seedling development.

Age of seed was found to affect emergence in the field. For Site 1, 1981-harvested Sunburst (Lot 1) emerged significantly greater than the 1982-harvested (Lot 3) for both scarified and nonscarified seed. At site 2,

emergence was lower for the more recently harvested seed (Lot 3), but scarified seed also exhibited lower seedling emergence than nonscarified seed for this lot. Reasons for this are not known.

In the field, scarification decreased emergence more often than in the greenhouse. Perhaps restrictive coverings became more weakened in the soil due to chemical reactions. Pathogen invasion of the seed may be a contributing factor to decreased emergence of scarified seed.

As we found in the laboratory and greenhouse, variation existed between Sunburst and SD33 syn-1 in the field also. Seedling emergence from nonscarified seed was always greatest for Sunburst (Lots 1, 2, and 3) compared to SD33 syn-1 (Lots 4 and 5). Although SD33 syn-1 (Lots 4 and 5) had lower seedling emergence, enhancement of emergence by scarification was greatest for the 1982-harvested seed of this lot (Lot 5).

Set II

Laboratory and Greenhouse Study

Scarification of freshly harvested seed significantly increased laboratory germination and greenhouse emergence.

Germination in the laboratory was increased with progressive planting dates, thus showing increased germination with time after harvest.

Germination in the alternating temperature germinator was consistently higher than that found for the constant 20°C chamber. This is in agreement with results from Set I. Overall germination in the alternating germinator was 37.7% compared to 20.3% for 20°C chamber.

Differences in germination ability and response to scarification were found between varieties in laboratory and greenhouse tests. In the laboratory these differences were statistically significant.

Germination percentages for all varieties of seed were greater after 15- and 30-second scarification compared to nonscarified seed. Germination of nonscarified seed and the increase in germination as a result of scarification was variety dependent, however.

Pathfinder (Variety 3), with a mean germination percentage of 12.0% for nonscarified seed, had the highest mean germination percentage for nonscarified seed but showed the least response to scarification and produced the lowest mean germination percentage for scarified seed. This variety was selected at the Nebraska Agricultural Experiment Station, Lincoln from a domestic collection of seed from Nebraska and Kansas being tested for winterhardiness, vigor, leafiness, late maturity, and rust resistance (Hanson 1972). Selective procedures used to produce this variety compared to the other varieties evaluated in this study may be a contributing factor in its response to scarification. Although it had a slightly higher germination for nonscarified seed compared to the other varieties, germination potential was not as great.

NDG-96598 which is selected from a native collection of seed from North Dakota had a mean germination of 11.0% for nonscarified seed. Although germination for nonscarified seed of NDG was similar to that of Pathfinder, response to scarification was greater for NDG. Thirty-second scarification of seeds of this variety did not improve germination over that of 15-second scarification.

Summer, a small-seeded, tall, leafy, and late-maturing variety was selected from a native collection from Nebraska at the South Dakota Experiment

Station (Hanson 1972). This variety had mean germination percentage of 8.5 and 39.6% for nonscarified and scarified seed, respectively, and consistently showed decrease in germination for 30- compared to 15-second scarification.

Sunburst, a large-seeded, vigorous, winter hardy, medium-tall, medium-maturity, leafy, upland type of switchgrass was selected from a native south-eastern South Dakota collection at the South Dakota Agricultural Experiment Station. Mean germination percentage of nonscarified seed was 6.4%. Although this variety did not show the highest germination for nonscarified seed, it exhibited the greatest response to scarification and produced the highest mean germination of 50.3% as a result of 30-second scarification. Dormancy of this variety appears more related to restrictions of the lemma and palea than for the other varieties tested. Large-seededness of this variety may also be important in its germination potential.

PM-SD-149 is a leafy upland type switchgrass of medium height. It was selected from a native collection from Forestburg, South Dakota at the Plant Materials Center, SCS, Bismark, North Dakota (Hanson 1972). In this study, this variety had a mean germination of 5.5% for nonscarified seed. Although the increase in germination from 15 to 30-second scarification was not greatest, this variety showed the greatest response to increasing scarification. Increasing amount of scarification would appear to continue to increase germination to a point. A deeper dormancy appears in freshly harvested seed of this variety compared to the others.

Greenhouse results were not consistent with findings in the laboratory for germination ability and scarification response of varieties, although varietal

differences were found. More emergence tests could better predict findings in the greenhouse.

Genetic differences between varieties as well as the environments from which these varieties were selected may be important in germination ability and degree and type of dormancy they exhibit. Environmental influences during seed development may vary from year to year, thus affecting germination and emergence each year.

SUMMARY AND CONCLUSIONS

1) Mechanical scarification shows promise for increasing germination and emergence of switchgrass.

2) Usefulness of mechanical scarification will be related to the degree of dormancy exhibited by the switchgrass lot being planted.

   a. If initial germination and emergence are high, scarification would be of little benefit.

   b. Field data indicated a possible adverse affect of over-scarification. Proper amount of scarification needs to be determined based on degree of dormancy to obtain full benefit of scarification.

3) Various factors must be considered when determining if scarification procedures would be of benefit for enhancing seedling vigor of switchgrass.

   a. Initial germination tests need to be conducted on seedlots used for planting. Although standard laboratory testing procedures produced higher germination than in the field, this is a method to determine if germination is low. Testing of scarified seed can also help determine its benefit. More tests are needed to determine better germination conditions and methods that would better predict findings in the greenhouse or field.

   b. Age of seed needs consideration when determining benefits of scarification. As found in this study, seed of greater than 1 year old germinated and exhibited greater seedling emergence than more freshly harvested seed. If seed could be allowed to age before use, germination appears to increase. However, if seed is needed for planting from the previous years harvest, as found in this study, scarification increased

germination and seedling emergence of the older seed lots but to a lesser degree.

c. Wide genetic and ecotypic variability for germination potential existed among the seed lots tested in this study. Therefore, scarification may be practical only for certain varieties or ecotypes.

d. Storage temperature also affects germination of switchgrass seed. Cold storage reduces the speed of seed deterioration. Higher storage temperatures, or alternating temperature, however, may enhance germination of more dormant lots of switchgrass. More work is needed on storage conditions to determine potential influences on germination success.

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